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A 2D kinetic approach of a collective load carrying in *Paratrechina longicornis* ants

Jordan Drapin*, Pierre-Alexandre Grott, Gerard Latil,
Vincent Fourcassié, Pierre Moretto

Centre de recherches sur la cognition animale (CRCA) - Centre de biologie intégrative (CBI), Toulouse, France

* Corresponding author: jordan.drapin@live.fr

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Introduction

Social performances of insects are inspiring robotics because of its remarkable cooperation in collective tasks. Yet, the phenomenon of collective transport among worker ants is often poorly understood, although it exists at least in 40g genera in different subfamilies of Formicidae (Hölldobler 1990). Cooperative transport, occurs when a group of individuals work together to move an otherwise unmanageable object.

Analysis of a load motion with a single-ant trajectory data, showed that while the combined force of the group determines the speed of the load, and it is individual informed ants that steer the direction of movement (Gelblum *et al.* 2015). However, analysing ant's locomotion is challenging due to the complexity of its body composed of a three-segmented trunk and 6 legs with six main segments. In fact, to study collective behaviour, current works are using one or few individual's trajectories or consider mainly the three main joint locations (Gelblum *et al.* 2015, Reinhardt *et al.* 2014).

To understand how an individual may influence the entire group, and to overcome this limitation, this study proposes to perform a 2D kinematic analysis of a collective transport model: the long horn crazy ant *Paratrechina longicornis* to get information of the participation of each ant. Our assumption is that the acceleration of the ant main segments (\vec{a}) reveals their action forces on the load according to the fundamental

physics principle (FPP, $\Sigma \vec{F} = m \vec{a}_g$) and explain the acceleration of the load center of mass (\vec{a}_g). The aim of this study is a first attempt to verify this assumption on the basis of the simplification of the forces to the accelerations measured thanks to the kinematics.

To study this assumption, we reconstruct the displacement of the body segments of each ant during a collective load carrying. We suggest that this tool can be used to undertake quantitative analysis, and predict new qualitative features of the influences that occurs during the collective transport process.

2. Methods

2.1 Model and bait calibration

For the purposes of our experiments, we sampled wild colonies of *P. longicornis* (detention certificate n. R02-2021-09-08-00002) collected in Fort-de-France (Martinique, France). In natural environment workers can carry insects often much larger than its own size (2.5–3 mm) and weight (0.5 ± 0.1 mg) by using impressive displays of cooperative transport (Wetterer *et al.* 2008). In the lab, to avoid the deformation of the load and mimic a large insect we design a plastic square (0.5x0.5x0.1 mm, 8.2 mg) coating with a meal worm solution. The size of the load was chosen to initiate a spontaneous collective behaviour with the limitation of seeing all the ants on the camera. For the experiment, workers from the entire colony were able to move freely from the nest to a foraging area through a walkway.

2.2 Setup

In order to get the kinematic of a group of ants that collectively carry a load, we filmed them from above on a walkway (20 x 2 cm). Three infrared strobe spots, synchronised with the camera sampled at 300 Hz, were used to illuminate the walkway, allowing us to reveal ant's joints. Then, the X, Y axes corresponding respectively to the antero-posterior and medio-lateral directions of the walkway, were defined and calibrated by digitising the points of a control object (Lego® brick) of known dimensions.

2.3 Polyarticulated model tracking

Using Vicon Motus (v.10, R&D Vision) the corners of the carried object as well as the location of 5 anatomic points (mandible extremities, neck, proximal and distal extremities of the petiol and abdomen) of each ant were digitizing and specified in an external 2D coordinate frame (fig. 1a). This allows us to build a polyarticulated model composed of four segments (head, thorax, petiol, abdomen) for each of the four ants and the load they transport.

2.3 Setup and anatomic segments tracking

Using Python (v3.12.2) the X and Y acceleration of each ant's segments were calculated with the position of the barycenter using the coordinates (X or Y) of the two points tracked and a 4 Hz Butterworth filter on the 925 frames of a video recording.

Results and discussion

A set of 24 points of interest allowed digitizing the ant's body segments thus the corners of the load carried (fig. 1a). They were then used to define a 2D stick model system. Trajectories of the center of each ant's body segments and the one of the load in the XY frame can then be followed (fig. 1b). The trajectory of the ants is straight during the majority of the record, then they turn clockwise during the last quarter of the record. The acceleration of the load and of the ant's (fig. 1c, d) calculated from these points have similar shapes during the 2 first seconds of the collective load transport (fig. 1c, d). After this period, the shapes of the curves vary, which can sign the time of the beginning of the rotation of the load occurring at the end of the recording. Indeed, the load rotates possibly due to the moment of force applied by the ants.

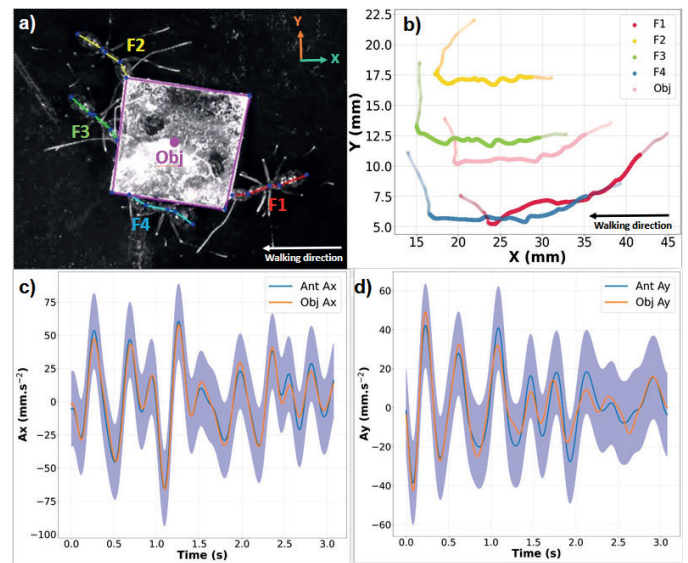


Figure 1. (a) Anatomic points locations on the ant's body (5 points), and on the load (4 points). The nest was on the left of the image. (b) Ant's and load center trajectories. (c, d) Evolution of the mean of acceleration of the ant's body (solid blue) and of the load carried (orange) respectively on X and Y axis. Blue-shaded regions represent the standard deviation around ant's values.

Other technics are used in ants to characterized the displacements of a subjects, such as the evolution of the variation of the center of mass (Merienne *et al.* 2019; Reinhardt *et al.* 2014; Drapin *et al.* 2021) using 3D kinematics (Merienne *et al.* 2021; Drapin *et al.* 2021; Arroyave-Tobon *et al.* 2022) and morphometry (Drapin *et al.* 2021; Aibekova *et al.* 2022). By combining the variation of the position of the center of mass with kinematics data regarding the precision of the morphometry, perspectives on the participation and influence of each individual during a load carrying in ants should be possible in term of forces and momentum.

Conclusions

The purpose of this study was to test a method to estimate the forces applied by four ants on a load they collectively carry. The results demonstrate the accuracy of the method to discern the translations of the object due to the action force of the ants. Further investigations will enable us to precise the method to consider both translations and rotations in 3D to finally address the forces and moment of force applied by the ants to understand the collaboration and the efficiency of each ant during the collective load transport. Finally,

this study could be useful in the study of biology and ethology but also help for biomimetic applications.

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Conflict of Interest Statement

The authors report no conflicts of interest in this work.

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